Heliostat Anton Pannekoek Observatory (Heliostat APO)

The Heliostat is placed on the roof of the building where the astronomical Anton Pannekoek Institute (API) is housed. Two telescopes in two classical domes are placed from the beginning on the roof for night time observations. The Heliostat is added on the roof near the two domes. The solar light is reflected by the Heliostat to the inside of one of the domes through a window, which can be opened for this purpose. The light is reflected downward through a tube to a room underneath the dome. Instrumentation is installed in this Heliostat room for projection of the solar image and simultaneously the solar spectrum, which is shown under the solar image. Both are visible at the same time in real solar light.

The following figures give an impression of the setup.
The last page is a drawing of the optical layout from roof to room via dome.

Figure 1. The installation on the roof of the building. The 4 orange arrows indicate the path of the light. The solar light comes to the first mirror M1, flat with diameter 305mm, which reflects the light downward to the second mirror M2, flat with diameter 203mm. The path from M1 to M2 is parallel to the rotation axis of the earth. M1 rotates in opposite direction around this axis and the downward beam remains along this axis during the day.

M2 reflects the light in horizontal direction to the first lens L1, diameter 150mm. The light goes from L1 to the nearby dome, where the light enters through a window, which can be opened. A first image I1 is formed inside the dome on short distance before the mirror M3, also flat with 203mm diameter. This mirror under 45° reflects the light downward. A long focal length of 9500mm was needed for the lens L1 to bridge the distance from the outside installation over the rails of the glass washer car to the dome and inside the dome to the mirror M3. The lens L1 had to be specially designed and fabricated. The primary image of the sun has a diameter of 90mm. A field lens L2 with 150mm diameter is placed between the primary image and the mirror M3.

The normal heliostats have near the roof floor a first mirror which reflects the light upward parallel to the rotation axis of the earth. This is a simpler solution, however does not fit on the available roof place for the heliostat relative to the domes on the roof. An additional mirror would be necessary making the outside light path more complex and longer. The unusual setup with reflection downward by M1 was chosen.

The downward reflection gave a challenge for the support of the moving mirror M1 without any deformation of the mirror to keep high resolution. M1 is most of the time pointed downward, but during the hours around noon in the summer it is pointed somewhat upward. The support points behind the mirror have to be stiff and without backlash when the mirror pointing is changing from downward to upward.

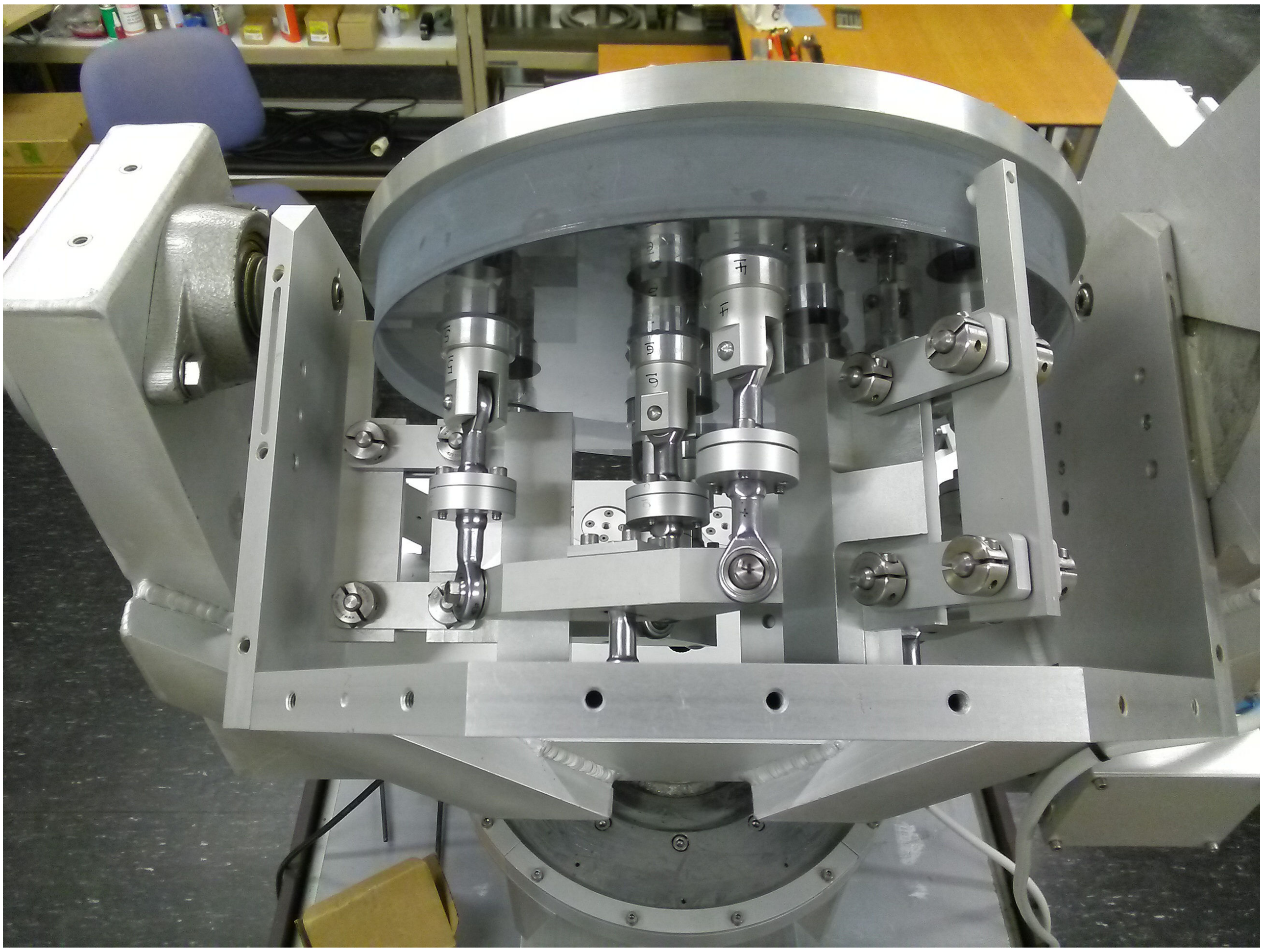


Figure 2. The support system of the first mirror M1. The mirror is supported in 9 points with 3 seesaws resulting in an equal distribution of the load over the 9 support points. Each seesaw carries 3 support points and can rotate in all directions around one turning point, which is realized by spherical plain bearings mounted in rod ends. The bearings are specially selected to be a little bit pre-stressed, hence without backlash but smooth rotation with low moment.
The mirror is of fused silica with low thermal expansion 0.55×10^{-6} per °C, which avoids disturbance of the high surface accuracy of peak to valley $\lambda/10$ (λ is 633nm) by temperature differences in the mirror, which is used outside. The mirror mount is of aluminum thermal expansion 27×10^{-6} per °C and parts of stainless steel thermal expansion 16×10^{-6} per °C. Coupled pairs of the same rod ends (vertical in photo) with backlash-free bearings are used for the connection between the seesaw ends and the small disks glued to the backside of the mirror. Each pair of two rod ends in one line after each other forms a stiff connection along the line of the two rod ends from a seesaw endpoint to a support point of the mirror, a small disk glued to the mirror. Free displacement exists in the transverse directions because of the bearings at the ends of the rod ends. Consequently, thermal expansion of the mount will not deform the mirror.
The lid on top of the mirror protected the reflecting front service against dust and the possibility of damage during the assembly of the mirror in the support system.

Figure 3. The downward light path from dome to Heliostat room.

Left side: The horizontal light beam goes through a small open window to the field lens L2 visible on top of the image by the incoming light, not only of the sun directly but also the sky light around the sun. The first solar image I1 of Ø90mm is 620mm in front of the field lens of Ø150mm. The 45° mirror M3 is behind L2 and the strongly illuminated part by the sunlight is visible through L2. The vertical tube for the downward light beam is visible in the lower dark part of the image.

Right side: The vertical tube comes through the ceiling downward. The unit hanging on the tube consists of two parts: The upper part is used for guiding the motors of M1 with a solar image on an electronic plate with 4 photocells. The lower part is used for projection of the solar image. The optical setup on the table is used for projection of the solar spectrum.

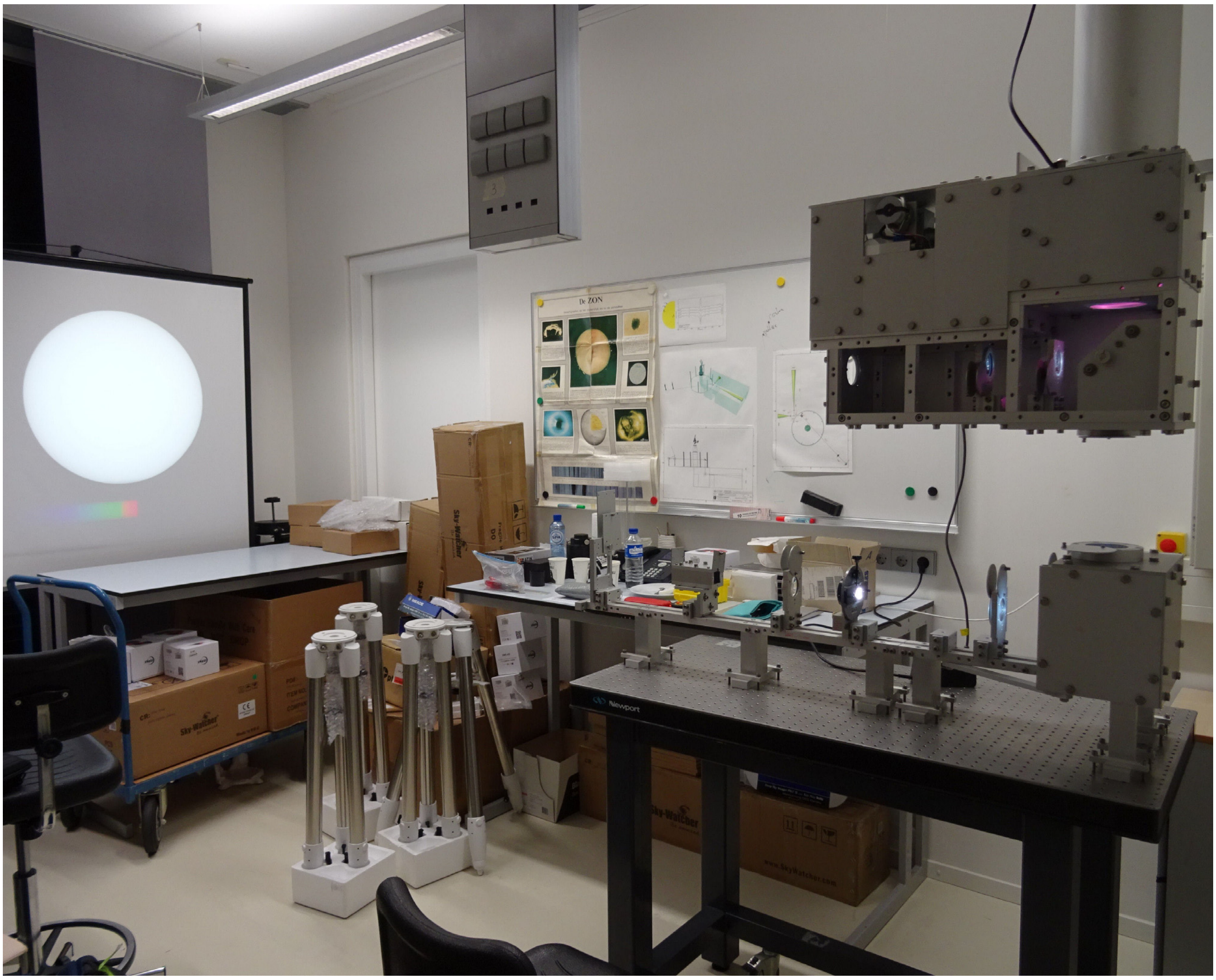


Figure 4. The setup in the Heliostat room from end of downward dome tube to projection screen. The lights in the room are on to show the instrumental setup.
The Photocells Follower is inside the closed upper part of the unit hanging on the downward tube. The light beam from above is falling on a 45° mirror M4. A small fraction of the light is reflected through a lens L4ph to the electronic plate with the 4 photocells where a solar image I2ph is formed with 28mm diameter, see the drawing with the optical layout on the last page. The upward signal cable from the electronic photocells plate to the motor controllers in the installation on the roof of the building is visible on the left side of the tube.
The light goes downward from M4 to M5, a 45° mirror which reflects 50% to the Projection Unit directly under the Photocells Follower. M5 is behind the vertical plate with 45° rim up-left directly under the visible light coming from above. The visible light on the left side near M5 is from the field lens L4. Between M5 and L4 is the solar image I2 with diameter 33mm. The very weak light more to the left is from the imaging lens L5. The hole, where the solar beam leaves the Projection Unit, is clearly visible. The Projection Unit is normally closed by side plates, which were taken away for the photos of Figure 3 and 4.
The projected solar image is visible on the projection screen on the left side with diameter a little bit more than 70cm (scale 1 to 2 billion. sun diameter 1.4 million km).
The 50% transmitted light from M5 goes downward through field lens L4d and from there to the optical table. The solar image I2d also with diameter 33mm is between M5 and I4d.
A 45° mirror M6 in the housing on the right side of the table reflects the light in horizontal direction to lens L5t visible on the left side of the M6 housing. This lens L5t forms image I3t with diameter 18mm on the slit unit, which is brightly illuminated by the solar light. Behind the slit unit are successively visible lens L6t, Direct Vision Dispersion Prism in housing and cylinder lens L7Ct.
The spectrum under the solar image is only weakly visible because of lights switched on in the room. Figure 5 and 6 on the next page are made with lights switched off.

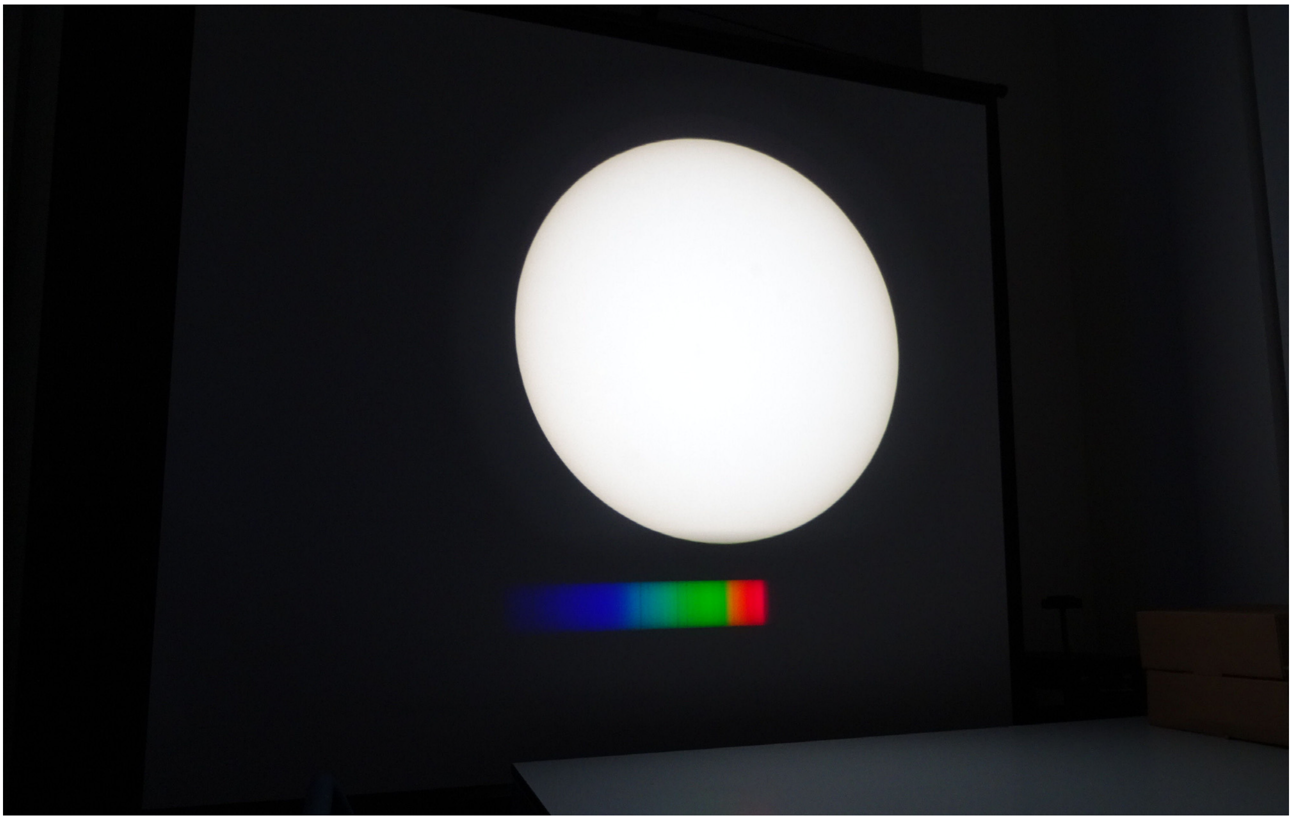


Figure 5. The projection screen with solar image and spectrum underneath.

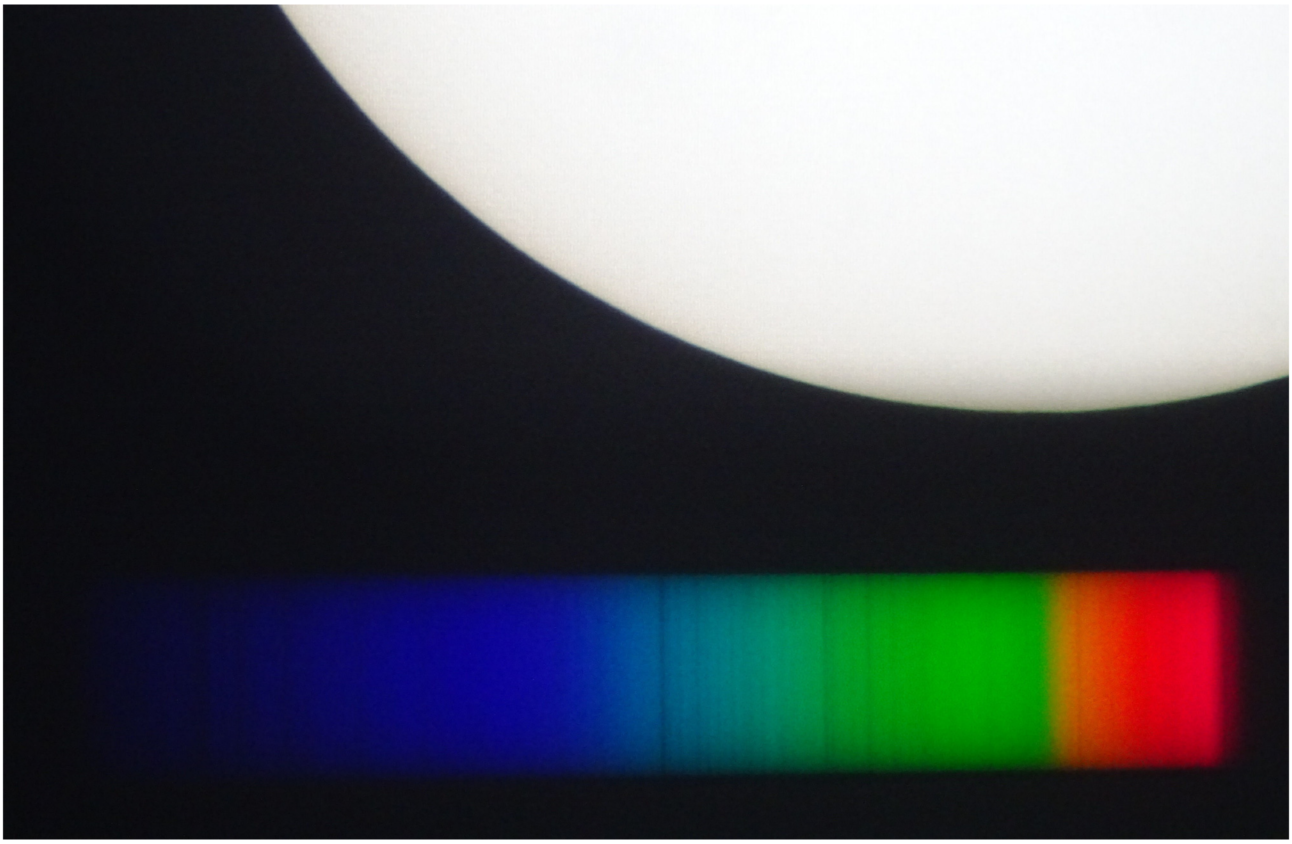


Figure 6. The lower part of the solar image with the spectrum shown more clearly.
Many spectral lines are visible. More spectral lines than in this photo are visible also in the violet by eye, when one is standing near the projection screen. The used camera for this photo is less sensitive than the human eye particularly in the violet.

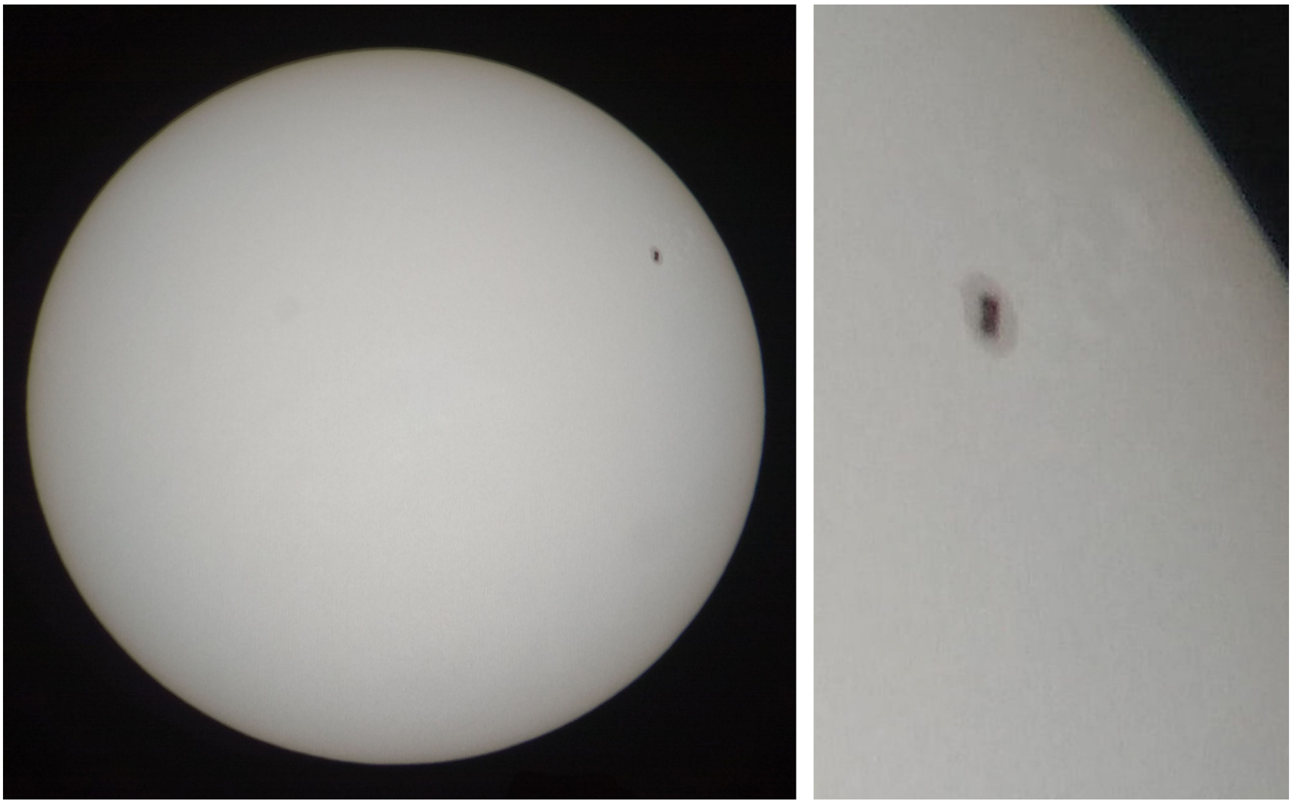


Figure 7. Sun with small spot, left total solar image projected, right detail with spot. The image is a photo taken from the projection screen. The detail is enlarged from this photo.

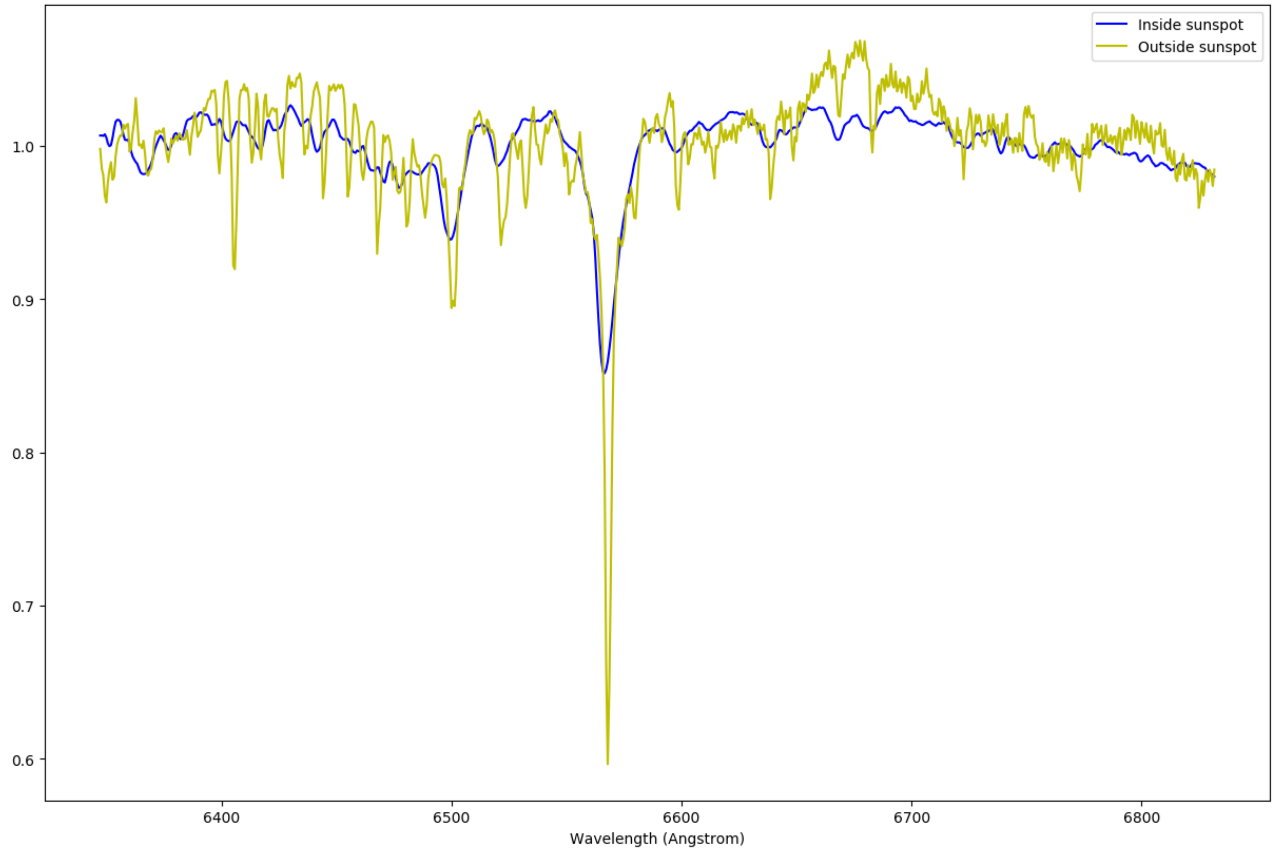


Figure 8. First spectra with Heliostat in the spectral region of the red Hα line (6563Å). Comparison of the spectra in- and outside spot. This figure is with raw spectra before precise wavelength calibration. Intensity is relative to the average intensity over the whole curve, which is in the spot much lower than outside.

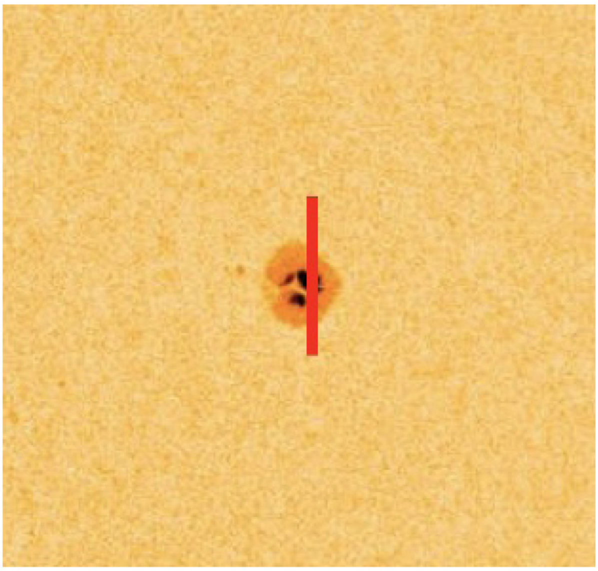


Figure 9. Sunspot 2741 with red line indicating slit placement.
Image is made with camera on the guiding hole of a Lhires III, a Littrow spectrograph with a resolving power of $\lambda/\Delta\lambda$ 17000 in the red part of the spectrum. The spectrograph was with an improvised set-up placed in the projected image of the Heliostat in front of the projection screen.

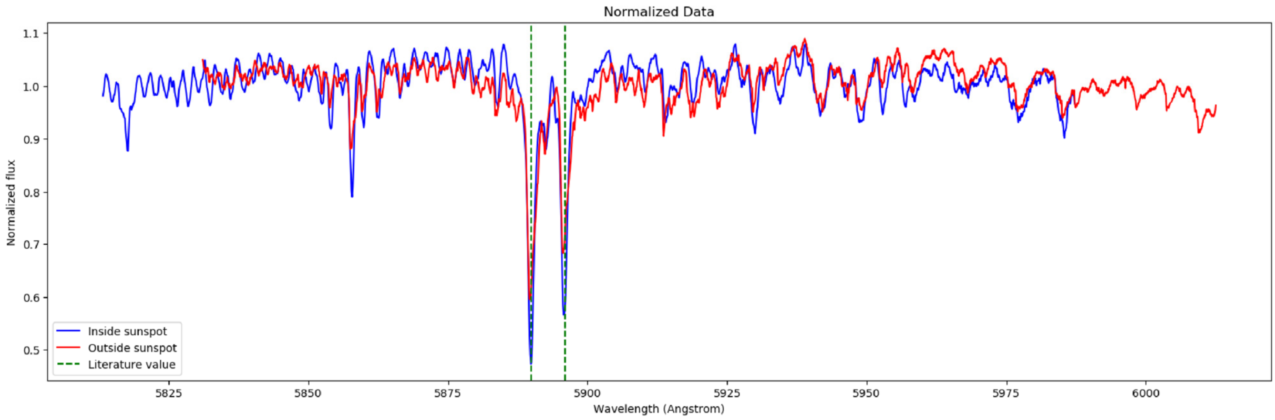
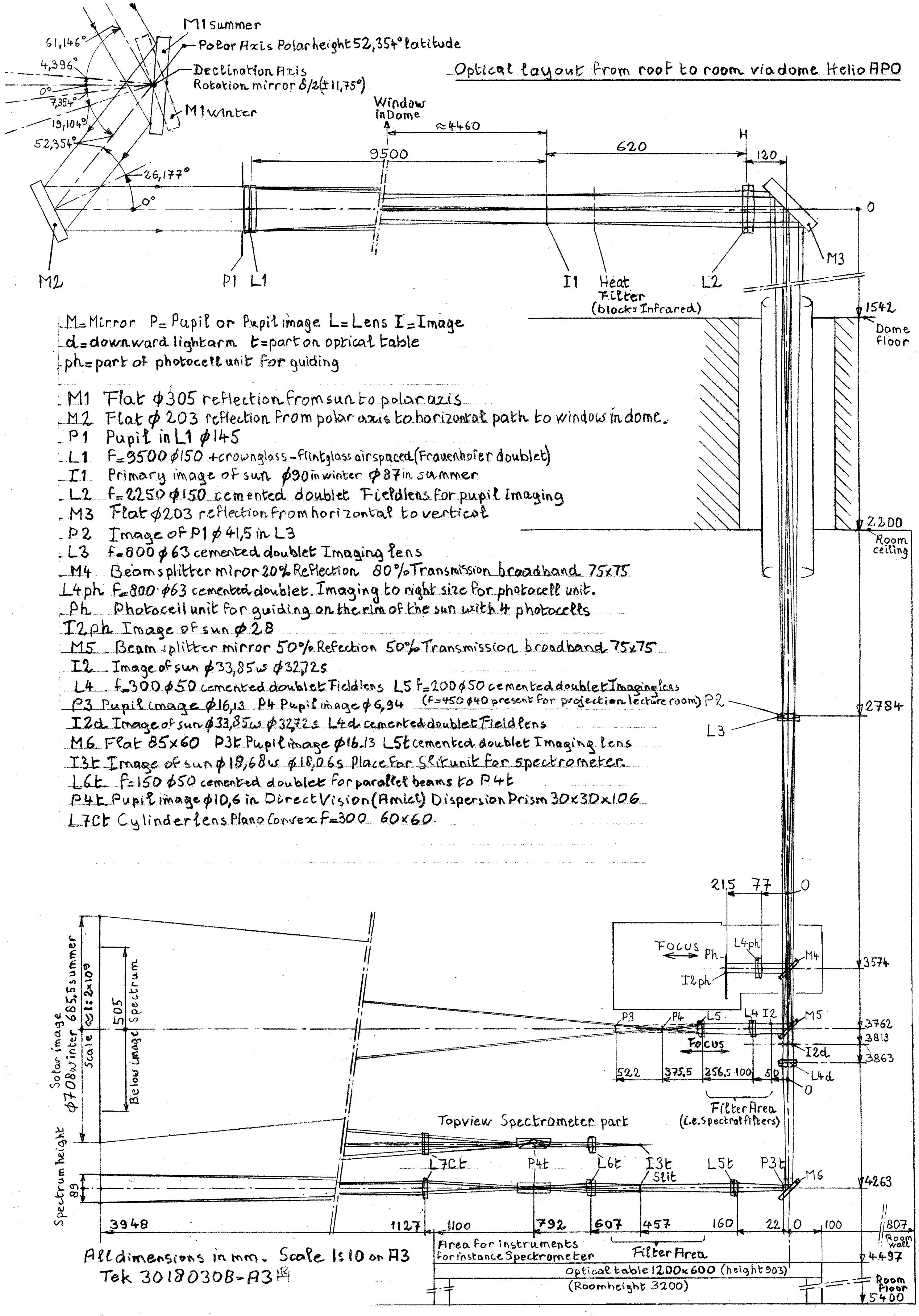


Figure 10. Spectra inside and outside the spot 2741 of the spectral region of the NaD lines.
This doublet has wavelengths of 5890 and 5896 Å. The spectra are made with the spectrograph placed in the projected image as described. The exposure times were 3 seconds inside the sunspot and 0.5 seconds outside.
A detailed description of the set-up of the spectrograph, the measurements and a further data reduction with the measurements is in:
Willem de Vries: Solar spectroscopy using the new APO heliostat 2019
Report of the Bachelor Project Physics and Astronomy of the Anton Pannekoek Institute.
The figures 9 and 10 are from this report.

Conclusions for the construction of a spectral setup for precise and fast movement of the entrance of the spectrograph over the solar image.
The experiences with the improvised spectral setup showed the new possibilities for comparisons of the spectra of different parts of the sun. It is important to construct now a reliable spectroscopic setup with precise and fast movement of the spectral input over the solar image. A problem with the improvised setup is the necessity not only to translate the spectrograph input over the solar image but in addition to tilt the input for pointing to where the light is coming from, the pupil image P4 in the Optical Layout on the next page. The solution for the setup to construct is a setup with the pupil image in infinity, a so called tele-centric setup. This can be realized with a field lens in front of the final image. This image can be much smaller than the projected image now. The spectral input can be realized with a fiber to the spectrograph. This will be possible with a setup to construct on the optical table next to the spectral projection setup.



Optical lay out from roof to room via dome.